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# Galactic binaries with eLISA

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**Abstract.** I review what eLISA will see from Galactic binaries – double stars with orbital periods less than a few hours and white dwarf (or neutron star/black hole) components. I discuss the currently known binaries that are guaranteed (or verification) sources and explain why the expected total number of eLISA Galactic binaries is several thousand, even though there are large uncertainties in our knowledge of this population, in particular that of the interacting AM CVn systems. I very briefly sketch the astrophysical questions that can be addressed once these thousands of systems are detected. I close with a short outline of the electro-magnetic facilities that will come on line before eLISA will fly and the importance of developing analysis plans using both electro-magnetic and gravitational wave data.

## 1. Introduction: Galactic binaries

The most numerous expected astrophysical sources for eLISA are Galactic binaries with orbital periods below ∼1 hour, in particular double white dwarf binaries. This was already realised early on (e.g. Evans et al. 1987; Hils et al. 1990), even though hardly any of such binaries were known at the time. In order to fit in the orbits of such ultra-compact binaries, the components need to be compact stars: white dwarfs, neutron stars or black holes.

By now, several classes of such binaries are know: double white dwarfs, white dwarf – neutron star binaries and double neutron star binaries. In addition, two classes of *interacting* binaries (rather than the above *detached* binaries) are know in which either a white dwarf or a neutron star accretes (hydrogen deficient) material from a white dwarf (like) companion. These are called AM CVn stars and ultra-compact X-ray binaries (see Solheim 2010; Nelemans & Jonker 2010, for reviews).

Based on these known systems and the general knowledge of binary evolution, the expected signals for eLISA have been derived, both from the individual known systems (when bright enough referred to as *verification sources* Ströer & Vecchio 2006) as well as the total Galactic population. These will be discussed below, as well as an outlook into what facilities will likely become available to astronomers before an eLISA like mission will fly.

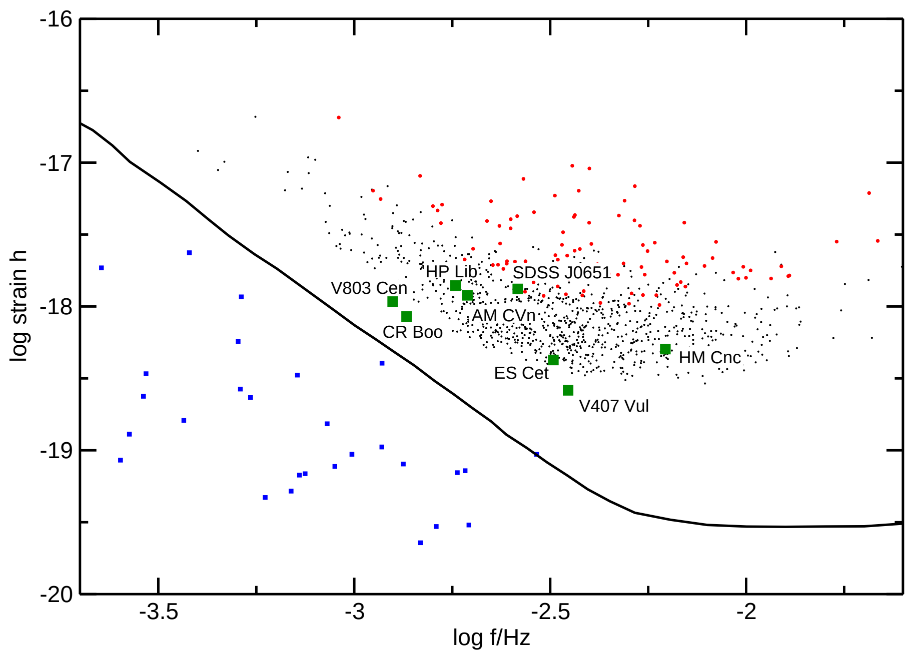


Figure 1. Sensitivity plot for eLISA showing the verification binaries (squares) as well as the thousand brightest expected systems from a population synthesis model of the total Galactic population of double white dwarfs. From Amaro-Seoane et al. (2012a)

## 2. Verification sources

Figure 2 shows the expected strain amplitude of the verification binaries compared to the eLISA sensitivity curve. There are 8 known binaries that are expected to be detected with S/N above 7: HM Cnc, V407 Vul, ES Cet, SDSS J0651+2844, AM CVn, HP Lib, V803 Cen and CR Boo.

Compared to earlier reviews (e.g. Marsh 2011; van der Sluys 2011; Nelemans 2009), there are two important developments. The first is the detection of the only detached verification binary (yet), SDSS J0651+2844 (Brown et al. 2011, see also Kilic, this volume), for which recently the orbital decay was measured which is consistent with the expected rate due to gravitational wave losses (Hermes et al. 2012).

The second is the detection of features in the optical spectrum of HM Cnc that show large velocity variation on the photometric period of 5.4 min (Roelofs et al. 2010). This finally decided the debate on whether this very short photometric period indeed was an orbital period and confirmed HM Cnc as the brightest verification binary. Fig. 2 shows the inferred geometry (in km!) from Roelofs et al. (2010).

## 3. Expected populations

Based on population synthesis calculations that have (as far as possible) been calibrated on observed populations, there are some hundred million double white dwarfs expected in the Galaxy (e.g. Nelemans et al. 2001b; Ruiter et al. 2010; Liu et al. 2010;

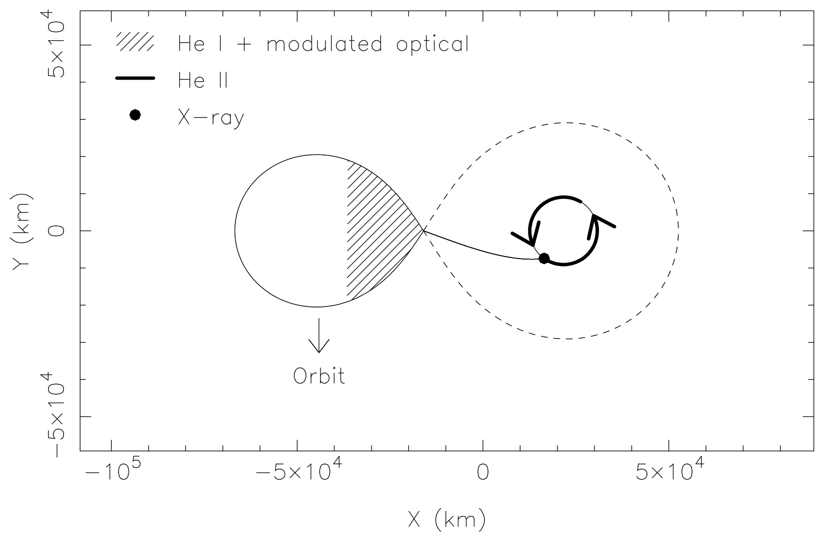


Figure 2. Inferred geometry from the spectral observations that show counter rotating He I and He II lines. The He II comes from the material that has hit the accreting white dwarf. The associated X-ray emission heats the side of the companion facing the accretor, causing He I emission. The figure is to scale with the axis in km. From Roelofs et al. (2010)

Yu & Jeffery 2010). For the original LISA mission, more than ten thousand systems would be individually detected (Timpano et al. 2006; Crowder & Cornish 2007; Littenberg 2011; Błaut 2011). For the the eLISA mission the number would be several thousand. In Fig. 3, the expected signal of such a theoretical population of Galactic binaries is shown.

The main problem for this calculation is that it is known that the number of AM CVn systems in the Galaxy is significantly smaller than predicted by these models (Roelofs et al. 2007, Carter et al. in prep.), at least at the longer orbital periods where they can be detected in a homogeneous way. It is unclear what the reason is for this discrepancy and even simply the whole population is much smaller, e.g. due to reduced stability at the onset of mass transfer (see Nelemans et al. 2001a; Marsh et al. 2004) or whether there is something special happening at longer periods (see Roelofs et al. 2007; Nissanke et al. 2012, for a more detailed discussion). This makes predictions for the number of AM CVn stars difficult at present. For the detached systems, the prediction of several thousand individual detections, most with periods between 5 and 10 minutes is more robust. The number of double neutron star and/or black hole binaries is much smaller, only several tens (Nelemans et al. 2001b; Belczynski et al. 2010), but for periods below ~30 min eLISA will detect the *whole Galactic population*.

## 4. Astrophysical relevance

So what will we be able to learn from those thousands of detections when LISA will fly? Briefly there are the following topics

**Common envelope** All (ultra)-compact binaries in which a white dwarf, neutron star or black hole accretes from a low-mass companion share one step in their previ-

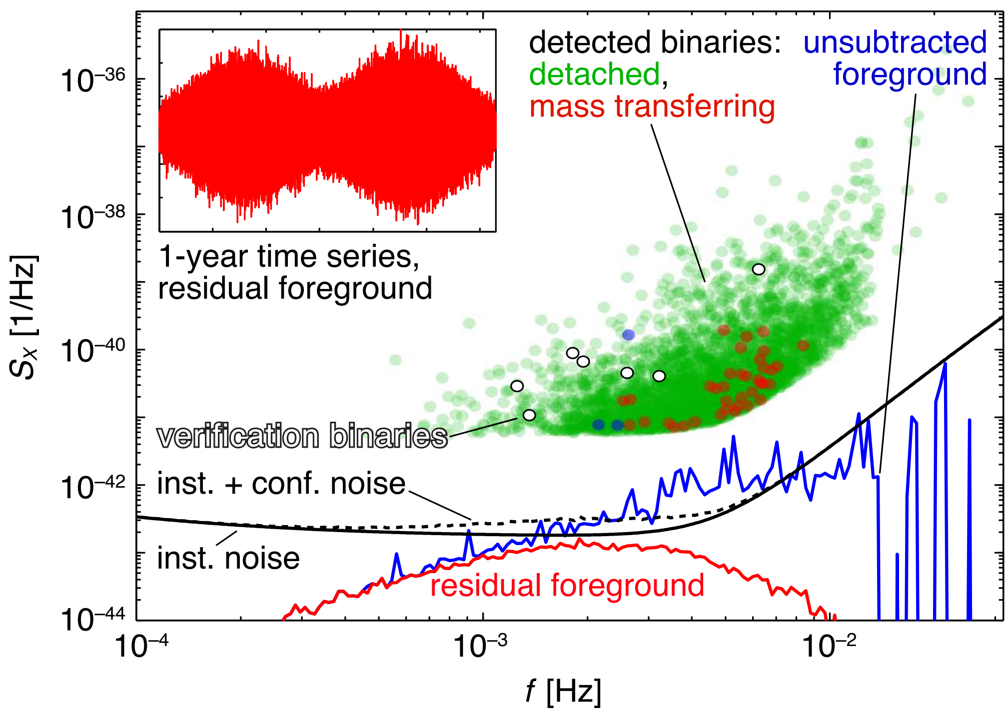


Figure 3. Summary of expected Galactic binaries for eLISA. The lines show the instrument noise, the unsubtracted and subtracted foreground and the sum of the instrument plus subtracted foreground noise. The points show the expected individual detectable binaries, including the versification binaries. From Amaro-Seoane et al. (2012b), based on Nissanke et al. (2012).

ous evolution. A step in which in some way a lot of mass and even more angular momentum is lost from the system. The simple idea (Paczyński 1976, and apparently Ostriker on that same conference) was that in some way a companion to a giant star enters its envelope and then, due to friction, spirals in while expelling the envelope. The results is a close binary consisting of the core of the giant with the companion. However, it is very uncertain how exactly this process happens and indeed in which situations it takes place. Double white dwarf binaries can be used to constrain the common-envelope phase (Nelemans et al. 2000; Woods et al. 2012) even with only a hand full of systems. The large number of very short period binaries detected by eLISA will give strong constraints. For more massive stars, either the detection of the double neutron star and/or black hole binaries or extrapolation of the results from the white dwarfs might also constrain the common-envelope phase.

**Type Ia supernova** are used to measure the accelerated expansion of the universe, yet we do not know exactly what systems lead to the explosion of the white dwarf. One of the proposed progenitor scenarios is the merger of two white dwarfs, exactly the population that eLISA will map in detail (e.g. Stroeer et al. 2011)

**H deficient accretion (and explosion)** Even if a merger is avoided when the two white dwarfs come into contact, or if the merger does not lead to a type Ia supernovae, the systems are interesting physics laboratories. The (rapid) accretion processes that will take place are particularly interesting, because in the systems there is no, or hardly any hydrogen. This potentially leads to all kinds of interesting phenomena, such as surface explosions, double detonations, helium novae and explosive shell ignitions, known as .Ia supernovae (Bildsten et al. 2007; Woudt et al. 2009; Guillochon et al. 2010; Pakmor et al. 2010; Fink et al. 2010; Dan et al. 2011).

**Binary interactions** Even before the double white dwarfs get into contact there are potentially other binary interactions. Tidal forces may heat the white dwarfs (e.g. Iben et al. 1998; Fuller & Lai 2012b,a; Valsecchi et al. 2012), signs of which may be seen in the new 12 minute binary (Brown et al. 2011). This in principle gives information about the internal structure of the white dwarfs. Also magnetic interactions may influence the orbital evolution.

**Galactic structure** Finally, for a subset of the individually detectable systems the distance is known (with accuracies randing from 10 to less than 1 per cent. Together with reasonable sky position errors (Fig. 4) this would allow to build a fairly accurate 3D map of where the binaries are in the Galaxy. That would give a completely new and different way to look at the structure of the Galaxy.

## 5. What will happen in the next 10-15 years?

Now that ESA has decided not to select eLISA for its L1 launch, we should reconsider the expected progress in the astrophysical questions in the next 10-15 years. This is difficult, so I will here just briefly mention the facilities that will come on line and some thoughts on their influence.

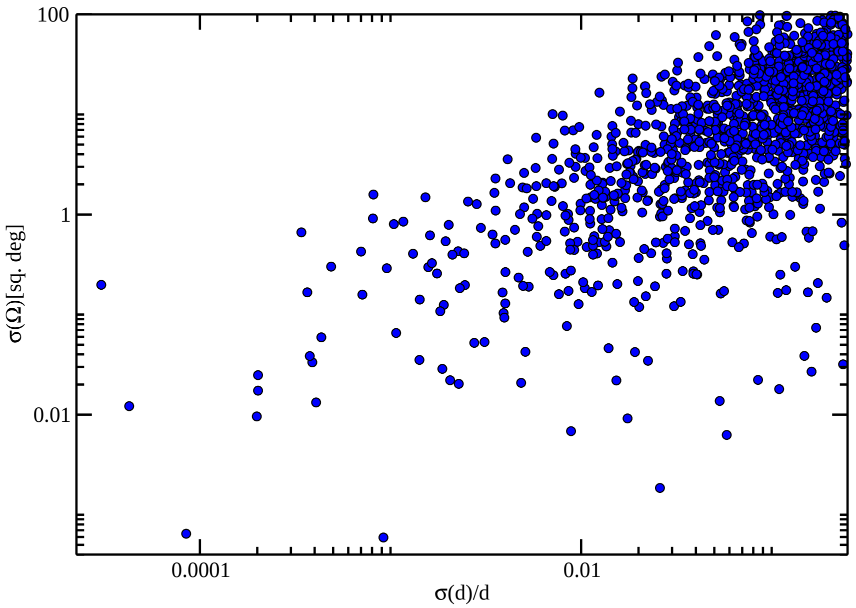


Figure 4. Error in distance and sky position for the double white dwarfs individually detectable by eLISA.

**ALMA** is a large US-European sub-mm array in Chile, that is currently performing its first observations. It should be completed by 2013 and will be able to make images with superb resolution. `http://www.almaobservatory.org/`

**JWST** is the successor of HST, with a 6.5m telescope and observing in the infrared. After long delays, the launch date is now expected to be 2018. `http://www.jwst.nasa.gov/`

**ELTs** are the generic term for the next generation of optical telescopes that should significantly increase diameter compared to current facilities such as Keck, the VLT, Subaru and Gemini. The European E-ELT, with a diameter of 38 meters is planned to become operational around 2022. `http://www.eso.org/public/teles-instr/e-elt.html` The US TMT or GMT possibly around 2020 `http://www.tmt.org/` `http://www.gmto.org/`. These ELTs could be quite interesting for Galactic binaries and eLISA because the optical/IR signatures of the vast majority of detectable sources will be well below capabilities of the current telescope. However, as shown in fig. 3 of Nelemans (2009), in the K-bad the majority of the systems should have magnitude brighter than about 29, the limiting magnitude for an instrument such as MICADO on the E-ELT.

**SKA** the Square Kilometer Array is the next generation radio telescope array, that should start construction around 2016. Precursor projects such as LOFAR, MeerKAT and ASKAP are currently becoming operational. `http://www.skatelescope.org/`

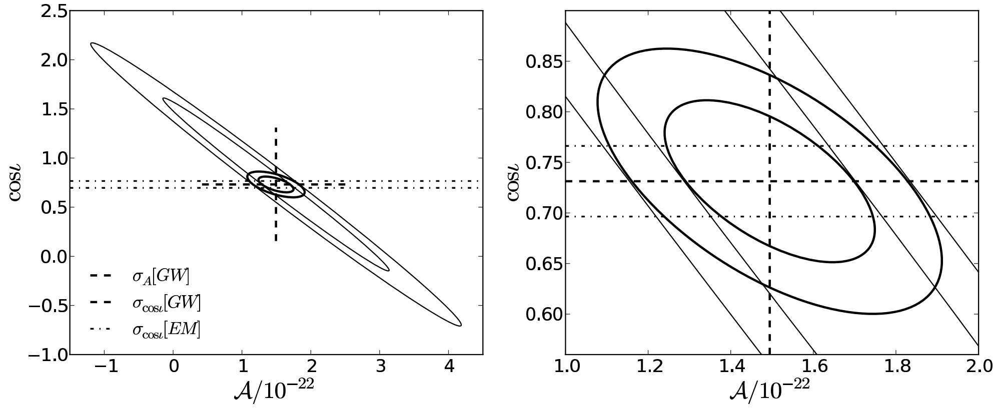


Figure 5. Error in amplitude and inclination for AM CVn and the improvement in the error on amplitude if the known inclination is taken into account. From Shah et al. (2012)

### 5.1. Transients searches

The other major development in the next decade will be the establishment of significant programs to look for transient phenomena in the sky in the optical/IR regime. Currently projects such as the Palomar Transient Factory (PTF) and Pan-STARRS are operational and discovering many strange and new transients. But also know classes of objects will be discovered at unprecedented rates. PFT, for example, has already discovered several new AM CVn systems. On the US side, there is the high-priority plan to build LSST, the ultimate transient machine by 2022.

### 5.2. GAIA

In 2014, ESA will launch the GAIA satellite which will scan the sky continuously to determine accurate positions of all stars brighter than about magnitude 20 and thus determine their parallax and proper motion (see Lindegren et al. 2008, for an overview of GAIA). GAIA will be an important source of complementary observations to eLISA. In particular, the fact that GAIA typically visits each position in the sky about 80 times, makes it possible to detect eclipsing double white dwarfs. Because the probability of eclipses increases towards shorter periods, these are expected to be typically rather short period (less than a few hours). A preliminary estimate (Marsh & Nelemans, in prep) suggest GAIA may detect some 200 of such systems.

## 6. Electro-magnetic counterparts

Finally, I briefly discuss some first efforts that focus on the benefit of joint electro-magnetic and gravitational wave data on individual binaries. For eLISA the number of individually detectable binaries that can in principle be found by modest size telescopes (with wide fields of view) is estimated to be between several tens and several hundreds (Littenberg et al. 2012).

Shah et al. (2012) investigated the use of prior electro-magnetic data for improving parameters that are estimated from the gravitational wave data. The strongest effect was found to be the large improvements in determination of the gravitational wave amplitude (i.e. the combination of masses and distance of the sources), if the inclination of the source was known from electro-magnetic observations, like in the verification binary AM CVn itself (see Fig. 6). The reason is that for the gravitational wave data there is a very strong correlation between amplitude and inclination (lower amplitude signals at favourable [i.e. face on] inclination cannot be distinguished from intrinsically stronger signals viewed at less optimal inclinations). Interestingly, this correlation disappears for edge on systems, yielding no additional gain in determination of the amplitude if the inclination is known. This means that, contrary to what one may think, optical data on eclipsing binaries, where there is the best chance of determining the inclination from electro-magnetic data, are not so useful. The other obvious parameters that are easy to determine from electro-magnetic data (once the source is found!) is the sky position. Investigations on how useful this information is are underway (Shah et al. in preparation). After these first steps a real integrated approach to joint electro-magnetic and gravitational wave data analysis should be developed (see also Littenberg et al. 2012)

## 7. Conclusions

Galactic binaries are also for eLISA a significant source class and the numbers of individually detectable systems still range in the thousands. There are currently 8 objects know that would serve as verification binaries for eLISA, one of them being a detached double white dwarf that shows orbital decay consistent with being only driven by GR. The expected population is uncertain, in particular for the interacting AM CVn systems. Once eLISA will fly this population is measured in great detail. All of the several tens of neutron star and black hole binaries with short orbital periods will detected by eLISA. This rich treasure trove of data will help to unravel several open issues in astrophysics, ranging from the progenitors of type Ia supernovae to the structure of the Galaxy. However, before eLISA will fly several new facilities will come on line that will contribute to the knowledge of the Galactic binary population, so joint efforts combining electro-magnetic as well as gravitational wave data need to be developed.

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